Operators' Accessibility Studies using Virtual Reality

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The development of fusion plants is more and more challenging. Compared to previous fusion experimental devices, integration constraints, maintenance and safety requirements are key parameters in the ITER project. Components are designed in parallel and we must consider integration, assembly and maintenance issues, which might have a huge impact on the overall design. That also implies to consider the operator’s feedback to assess the feasibility of accessibility or maintenance processes.

Virtual reality (VR) provides tools to optimize such integration. In 2010, the CEA IRFM decided to upgrade its design tools, by using VR during the life cycle (from design to operation) of a fusion component. The VR platform is intensively used in the design and assembly studies of WEST components. In particular, feasibility of the assembly scenario is assessed by the operators involving in the real assembly work.

To study this aspect, the use of static manikins is quite frequent in the industry. However, more complex studies, like the feasibility of assembly and maintenance tasks in complex and very confined environments, require enhanced features such as dynamic and biomechanically realistic virtual humans. We also study the contribution of tactile feedback to improve physical presence and interaction in the virtual environment (VE), which is very important for the validation of a given task's feasibility and the ergonomic evaluation of the posture and gesture of the operator. In particular, we show that adapted behavior in respect to physical elements of the VE can be obtained using a dynamic co-localized representation of the subject's body and a pseudo-haptic tactile feedback.

In this paper, we present integration studies involving operators and recent advances in the assessment of maintenance feasibility.

Keywords: Virtual Reality, WEST project, Accessibility study, Avatar, Vibrotactile

1. Introduction

Since 1990, industry has seen the interest of Virtual Reality (VR). By creating interactive and versatile environments and mock-ups, VR allows, inter alia, to evaluate the accessibility, feasibility and ergonomics problematic of assembly and maintenance tasks, in early stages of the design process. It could have a very positive impact, in terms of cost and time, by reducing the need for physical mock-ups and validating (or not) early designs. In the context of fusion plants, the integration constraints, maintenance and safety requirement are key parameters for the design. VR technologies are very efficient to optimize such integration, integration within parallel designing processes while taking into account assembly, maintenance and safety issues.

The role of operators in future facilities also needs to be studied. The human factor takes an important role, since the operator often has to interact with elements in a very tight and confined environment. Due to that, simulation in VR has to take into account this specificity. However, if visual rendering of a complex confined space is nowadays satisfying, haptic rendering remains difficult, if not impossible. This is a problem, since, to validate a maintenance task, the operator has to maneuver in a confined environment, to pay attention to his/her whole body and adopt a correct posture with respect to the environment (see Figure 1). Studies like the feasibility of assembly and maintenance tasks in complex and very confined environments require enhanced features such as dynamic and biomechanically realistic virtual humans (also called avatars) and need a substitute for the missing haptic feedback.

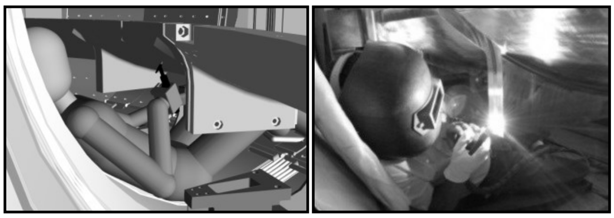

Figure 1: Welding task simulation in Virtual Reality and with a real mockup.

2. Approach

While obtaining a force feedback is relatively straightforward using a haptic force device, these systems cannot be applied to all types of scenarios. They are not satisfactory to interact with a complex Virtual Environment (VE), in particular when the whole body is

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involved. Two other interaction metaphors can be studied to "replace" haptic perception. The first one is the addition of a tangible interface, such as physical elements within the user's workspace, creating a mixed reality [1], [2]. However, that can be difficult to implement in the case of complex environment. The second one is lighter pseudo-haptic systems for representation of localized information such as contact points, without restriction of mobility (they can be wearable). This last metaphor can be implemented using vibrotactile interfaces. We propose to use vibrotactile feedback as a substitute for force feedback, to make users aware of impending or actual collisions in highly constrained spaces. This type of feedback has shown interesting result in the case of guidance [3], [4] and also in collision awareness [5]–[7].

The democratization of VR HMD (Head Mounted Displays) such as the Oculus Rift and HTC Vive raise the problem of the representation of the subject's body. By default, the subject does not see his/her own body when using such a device. We propose to use a dynamic and co-localized representation of the subject's body to improve the operator's behavior regarding physical elements of the VE.

We experimented these factors (virtual body and pseudo-haptic feedback) in two experimentations that cover the two main kinds of situations we encounter: displacement in a confined environment and manual operation from an almost static position (limited displacement of the operator).

3. Experimental Study

1.1. Adaptive behavior

We realized a first experimentation to analyze the factors needed to obtain an optimal adaptive behavior. The lessons that can be learned from this simple scenario are intrinsically linked to some of our studies involving an operator's displacement within a confined environment. Our general hypothesis was that, when the subject wears a HMD, the presence of a (visual, co-localized) virtual self favors perceptual calibration of the body/environment relationships (and the processing of body-scaled information [8]). Furthermore, in line with recent studies [7], we supposed that vibrotactile feedback (signaling, impending or actual collisions) might also contribute to behavioral calibration. Please refer to [9] for details.

In this experimentation subjects (twenty male subjects voluntarily) were asked to walk straight from a starting point to a target position. The VE was composed of a three meters wide corridor. A sliding door was positioned in the middle of the corridor. The door could be opened with five different width apertures: 40, 50, 60, 70, 80cm (Figure. 2 C-D). We studied the instinctive behavior (affordance) of rotating our shoulders to pass through a narrow aperture; the rotation should depend of the aperture width.

Subjects were equipped with an HMD Oculus Rift DK2 device and a vibrotactile device that we developed previously [7]. Two vibrators were placed on the shoulders side. The subject's all-body position was obtained by an optical tracking system (ArtTrack®) (Figure 2, A) in order to record the subject's movements. These positional data could be connected to a real-time and co-localized virtual representation of the subject's body (Figure 2, B).

Figure 2: **A.** One subject in the physical environment. He wears the HMD and is equipped with body markers. **B.** A representation of the subject passing though the aperture. **C.** Subjective view inside the HMD.

We studied two aspects. The first one is the type of feedback. It could be only visual or augmented with vibrotactile stimulation. The vibrotactile feedback operates as a radar (similar to those in cars). When the subject approaches his shoulder from a virtual object (a side of the door in this case) a discontinuous vibration is sent to the corresponding actuator (with an intensity inversely proportional to the distance). The second condition is the presence (or not) of a virtual body also called "Avatar" (co-localized with the subject's body).

Figure 3: The recording of all-body movements are used to build a co-localized avatar. The spheres' centers represent the vibrating actuators position on the subject's shoulder. Their size represents the spatial domain in which the actuators were active (that is when the subject shoulder's distance to a virtual object was inferior to their radius).

Results show that, in all conditions, subjects exhibited an adaptive behavior: rotating the shoulder to pass through a narrow aperture; in the same proportion as the outcome of previous studies [8], [10]. This result confirms that adaptive behavior, previously observed in natural conditions and in a CAVE (4 screens VR rooms) setup, is similar when participants wear a Head-Mounted Display (HMD).

The collisions percentage analysis between the subject's shoulders and the door shows interesting results. For small apertures, results show that both factors significantly affected the occurrence of collisions, these being minimal when both vibrotactile feedback and virtual body were present. The avatar and the vibrotactile feedback allow subjects to calibrate the perception of their body-environment relationships (using body-scaled information).

1.2. Feeling of contact

An important part of our studies involve manual operation with limited displacement of the body. The second experimentation was based on that kind of scenario. In this experimentation, we deepened the study of vibrotactile feedback. Our general hypothesis is vibrotactile feedback and especially multi-localized vibrator, contribute to enhance visuo-proprioceptive consistency. We use the term visuo-proprioceptive consistency to refer to the spatio-temporal coherence between the operator's and avatar's kinematics. This concept can be linked to the concept of kinematic symmetry proposed by McMahan [11]. Spatio-temporal coherence describes a bi-directional link of interaction. The avatar must adopt the same posture as the user, being co-localized with the user. Conversely, the user must integrate the posture limitations imposed on the avatar by the virtual environment (VE).

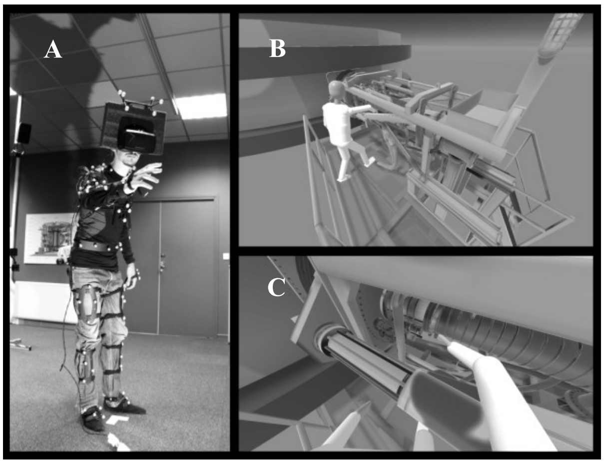

Figure 4: **A.** Subject in the experimental setup. He wears the HMD, and he is equipped with an ART target for the tracking of the head's translational movements. **B.** The virtual environment **C.** Subjective view inside the HMD.

The experimentation is based on a study case from the CEA WEST assembly. Subjects (twenty eight subjects voluntarily) were asked to reach targets (semi-transparent sphere) that appear in the VE with their right hand. We asked them to adopt the more fluid and natural movement as possible. The environment represents a part of a WEST facility. The VE was composed of a platform to access the back of an ICRH antenna (Figure 4 - B). We studied several Vibrotactile conditions: without activation of any actuator, with a single vibrator on the upper side of the hand or with ten vibrators along the arm (Figure 5).

Subjects were equipped with an HMD Oculus Rift DK2 device and a vibrotactile device. Ten vibrators were placed all along his arm. Subject's all-body movements were tracked (Figure 4 - A) and used to connect to a real-time and co-localized morphological valid virtual representation of the subject's body (Avatar) (Figure 4 - B).

In this experimentation, the avatar cannot pass through elements of the virtual environment. The avatar's members are blocked at the surface of the object, but nothing prevents the subject from continuing his movement. These situations create a visuo-proprioceptive inconsistency: the avatar and the subject do not have any longer the same posture.

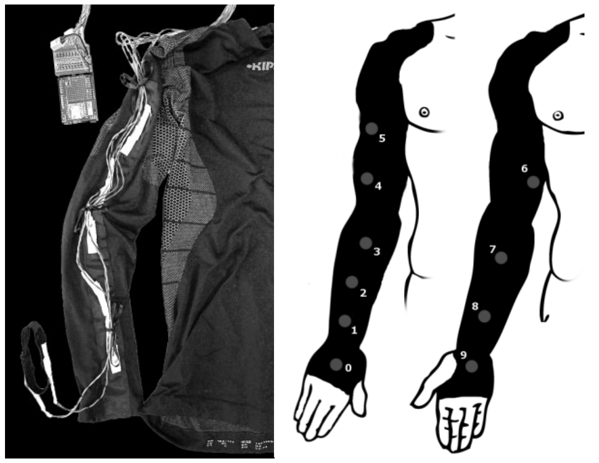

Figure 5: Vibrotactile arm suit device with ten actuators (left). Vibrators' position along the arm. In the condition with a single vibrator only the vibrator '0' is used (right).

Preliminary results from this experiment show that the vibrotactile feedback reduces visuo-proprioceptive inconsistencies. Also, subjective data (post-hoc questionnaire) show that the majority of subjects found that the extra information given by the multi-localized vibrotactile device is relevant. It allows a fast location of contact points without visual feedback. We also asked for participation in the experiment to CEA operators, who have several working years of experience with ToreSupra/WEST facility. Their feedback was positive and they estimated that the setup: VR device, co-localized avatar and multi-vibrotactile feedback is a very useful tool to evaluate accessibility.

4. Conclusion

Within the frame of the use of VR simulations for assessing complex assembly tasks performed for the WEST project, one approach mixing a dynamic and co-localized representation of the subject's body with a multi-localized vibrotactile feedback as substitute of contact tactile clue has been tested. Results show that these two factors allow calibrating the perception of the operator's body-environment relationships and enhance visuo-proprioceptive consistency. The extra information, offered by a localized vibrotactile feedback, allow a fast location of contact points without overloading the visual sense and preserve a visuo-proprioceptive coherence. We conclude that associating these two aspects to enhance the validity of assembly and maintenance simulations realized in virtual reality.

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